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Iron-Containing Coatings on Asbestos-Cement Pipes Exposed to Aggressive Water

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IRON-CONTAINING COATINGS ON ASBESTOS-CEMENT PIPES EXPOSED TO AGGRESSIVE WATER

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16. ABSTRACT

Coatings containing iron were found on asbestos-cement pipes exposed to a range of water qualities from very aggressive to nonaggressive. Under aggressive water conditions iron coatings had a granular, porous structure that prevented asbestos fibers from being exposed on the surface of the pipes but did not necessarily prevent leaching of calcium from the interior of the pipe (several millimeters from the surface). A modified durometer showed promise as a hand-held instrument for the assessment of A/C pipe softening in the field. The numerical value of hardness given was related to the amount of calcium leached from the pipe but was not directly related to the amount of fiber exposed on the surface of the pipe.

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IRON-CONTAINING COATINGS ON ASBESTOS-CEMENT PIPES EXPOSED TO AGGRESSIVE WATER

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Asbestos-cement (A/C) pipes are used in many drinking water distribution systems without problems. However, under certain conditions, A/C pipe will be attacked by the water it is carrying and show signs of deterioration (1). In severe cases the structural integrity of the pipe is adversely affected. On a lesser scale, deterioration of the first few hundred micrometers of the pipe material may expose fibers on the surface which is in contact with the water. Concern over the presence of asbestos fibers in the drinking water has caused some water utility personnel to evaluate their A/C pipe in regard to its potential for releasing fibers to the water. Although AWWA has published an aggressiveness index (AI) to help utilities decide whether or not their water is aggressive to the degree that it would harm the structural integrity of A/C pipe (2), there has been criticism of using the AI as a predictor of potential fiber release (3). The AI (Figure 1) is derived from the Langelier Index (4) based on calcium carbonate saturation considerations. The potential for non-calcium carbonate materials to form protective coatings is not estimated by the AI. That is not to say that the amount of calcium carbonate saturation is not an important factor in the attack on Portland cement materials. After studying the deterioration of Portland cement concrete in natural waters, Muller (5) concluded that if a water was not saturated with calcium carbonate, it was aggressive to concrete. Coatings may help bind fibers to the pipe but not necessarily stop water from attacking the pipe.

PROTECTION BY IRON

Coatings containing iron have been implicated in preventing corrosion of cement and asbestos-cement pipes in several studies. In cold-water piping systems composed of cement-lined pipes, Uhlig (6) reported evidence that small cracks were automatically plugged with a protective reaction product of rust combining with alkaline products leached from the cement. In an English survey described in Lea (7), A/C pipes carrying mine waters containing some sulphuric acid, arising from the oxidation of iron pyrite ores, and large amounts of sulfates, showed no appreciable deterioration in some 10 years. Thick coatings of hydrated ferric oxide had deposited inside the pipes, forming a protective layer. Buelow et al. (1) described one municipal A/C pipe system in which the water had an aggressive index ranging from 6.0 to 7.5, a severely aggressive water. No high asbestos fiber counts were found and except for a slight softening of the surface, there were no signs of deterioration. All of the A/C pipe excavated from that system was coated with what appeared to be iron rust, which Buelow speculated may have protected the pipe from deterioration. Buelow's pipeloop (1)

produced similar results. He found that the iron dissolved in the water from pump equipment was precipitated to provide a protective coating to the A/C pipe, even under highly aggressive water quality conditions. This coating reduced both the leaching of calcium from the pipe matrix and release of asbestos fiber. Schock (2) described one pipe coupon tank test where iron was addded to system. The water had a pH of 7.2, a total alkalinity between 18 and 21 mg/L as $CaCO_3$, 9-25 mg/L of calcium, 0.1 mg/L of zinc and 0.1 mg/L of iron. The AI was 9.4. After months of operation in which the calcium level increased from 9 to 25 mg/L as $CaCO_3$ a light coating was seen on the A/C pipe coupon. Schock concluded that the iron and zinc coating helped to bind the fibers even though the pipe surface was softened from water attack as evidenced by the calcium leaching and visual appearance of the coupon.

Kristiansen (8) found a thin deposit on the inner surface of the A/C pipe in his seven year study of aggressive Oslo, Norway, water. The coating was composed mainly of organic matter (ignition loss at 600°C), but also ferrous hydroxide and silicic acid. An increase in the amount of calcium released from the pipe after the sludge was removed indicated that the deposit had acted, to a certain extent, as a protection against attacks by aggressive water. Meyer (9) also found iron-containing coatings apparently protecting some A/C pipe distribution systems in Germany.

In order to confirm and study further the apparent protective effect of iron on A/C pipe a project was initiated to evaluate the coatings on pieces of A/C pipe from several sources. Methods were developed to assess the condition of A/C pipe is a more quantitative and comparable way than had been used in the past.

MATERIALS

A number of pieces of pipe taken from drinking water systems throughout the United States had been sent to the U. S. Environmental Protection Agency Research Center in Cincinnati, Ohio, in conjunction with a number of different projects. The samples chosen for study are given in Table 1 along with a brief description of parameters of interest. Pipe samples were chosen to represent a range of water qualities. The aggressive indices ranged from a very aggressive 6 to a non-aggressive 13.

In System J (1), the water being transported was very aggressive with an initial AI = 5.67. Fiber counts over 100 million fibers per liter were found at three points in the distribution system. Upon removal of a piece of pipe that had been in service for five years, Buelow (1) observed that it had been attacked, and the cement binding compound appeared to have been dissolved to a depth of about 0.3 cm. State water records showed that 90% of the time during the past few years, the iron content of the source water had been 0.1 mg/L or less. The system was composed entirely of asbestos cement pipe and contained no cast-iron pipe. The velocity of the water in the system was thought to be about 2 ft/sec.

System K carried a very aggressive well water (AI = 7.5) with an iron content of the water at the well of between 0.04 and 0.1 mg/L. However, the system was fed by gravity through a metal storage tank. The tank had been coated with an asphaltic compound but there were signs of rust on it. The piece of pipe sent to EPA was from a 4-inch main installed in 1966 and removed in 1981. Iron in the system water near where the pipe piece was taken was determined to be at a level of 0.16 mg/L. The

AI at this point in the distribution system had risen from 7.5 to 9.1. The pipe piece had a definite orange-looking coating.

System L carried waters from several well sources. AIs for the well waters ranged from 8.8 to 10.1. Iron content of the source waters ranged from 0.04 to 5.6 mg/L. During routine work on a 10 year old 6-inch main, a utility crew noted that an orange coating on the interior of the A/C pipe was peeling away and revealing asbestos fibers. A piece of the pipe was sent to EPA for analysis.

Water quality data from System M suggested a moderately aggressive water with an AI around 10. The iron content of the water was less than 0.1 mg/L. The pipe piece sent to EPA was from a 3-inch diameter A/C main that had been in use for 40 years.

From System N, a pipe "cookie" (a round piece cut from the side of a pipe) resulting from a routine tapping was sent to EPA for analysis. The piece was from an 8-inch diameter main installed 20 years earlier. A sample of water taken slightly upstream of the cut showed the water to be aggressive with an AI of 10.4. Other data indicated that the level of iron from the water source was 0.0 mg/L.

The System I pipe piece (1) was taken from a distribution system in which the finished source water would be considered to be very aggressive (AI = 7.5). Although very high asbestos counts were expected from water sampling, this was not the case at two points in the distribution system. At a third point in a deadend part of the system, high fiber counts were concluded to be a result of stirred-up debris that had probably collected from pipe tappings rather than deterioration of the pipe. All the excavated A/C pipe in the system was found to be coated with what appeared to be iron rust, which in Buelow's opinion may have protected the pipe from deterioration. The iron content of the finished water going into the system ranged between 0.1 and 0.15 mg/L. However, in addition to the 54 miles of type II A/C pipe, the distribution system also contained some 50 miles of cast iron mains that depending on the presence or absence of linings might have contributed to the iron content in the water when the direction of water flow varied in the system. The only pipe piece available for examination was from the deadend section. Analysis of the water chemistry at this point in the distribution system showed an AI of 11.6, a considerable increase from the initial AI of 6.0 - 7.5 of water entering the system. The velocity of the water would be close to zero in this deadend area.

A semicylindrical sample of 6-inch A/C pipe was received from System O. It had been part of a pipe placed in service in 1967 and removed 15 years later in 1982. The main had primarily carried water from one source (AI = 11.8), however, during some months of the year and during drought periods other sources were used. The other sources also had AIs slightly less than 12.0. The iron content of the water was less than 0.01 mg/L. A Brinell hardness test had been performed by the city laboratory using a 10 mm ball and 500 kgf loading applied by a Tinius Olsen Locap machine for less than 5 seconds. The laboratory found a Brinell hardness value of 45 for the pipe piece, which, when compared with a Brinell hardness value of 83 for a new A/C joint coupling drawn from water department stock, suggested that the used pipe may have lost some of its hardness. The laboratory cautioned, however, that the new joint coupling might not have represented the original hardness of the pipe taken from service.

From System P, 8 pipe plugs from routine tapping operations were sent to EPA after high fiber counts were determined in the system. The water distribution system from which these pipe plugs were taken carried a combination of surface water and ground water extracted from deep wells. The water quality constantly varied depending on the ratio of surface to ground water being utilized and seasonal variations of surface water chemistry. The water quality data suggested that the water was slightly aggressive at times with an AI of 11.7 but that usually the AI was over 12.0 (average AI = 12.3). The iron content ranged from 0.0 to 0.5 with an average of 0.02 mg/L. Several of the pipe pieces had an intermittent light tan coating but on some pieces no coating was seen. The sample analyzed was the oldest piece of the 8 pieces sent. It came from an 8-inch pipe installed in 1961 and removed in 1979. It had no obvious coating. Observations of the pipe surfaces had previously led one researcher to conclude that the pipe was not releasing fibers and that the high fiber count water sample that had been collected at a fire hydrant represented old tapping debris rather than system deterioration.

In System Q asbestos-cement pipes had been in service for approximately 20 years before a piece of pipe was taken and sent to EPA in 1980. The pipe sample, taken from one of the oldest lines in the city, had carried water from several sources during its service. Prior to 1964 the water source had been local ground water and essentially no records of its quality were kept. From 1964-1972 the pipe carried water from a river source with an average AI of about 12.2. From 1972 until when the pipe was removed the source of water carried by the pipe usually had an AI greater than 12.0. The lowest recorded AI had been 11.9. No data had been provided concerning the iron content of the water but a brown coat was clearly evident on the pipe.

The water in System R was treated with lime to produce a positive Langelier Index of about +1.7 and thus also had an AI over 13.0. A pipe "cookie" from a routine tapping of a 6-inch main had been sent to EPA. An obvious white coat was visible on the surface of the sample.

In addition to the field samples, 2 experimental tank setups were constructed following the description in Buelow (1) except that plastic tanks were substituted for the stainless steel tanks. Both tanks contained very aggressive water AI < 10. One tank contained a piece of sacrificial cast iron. The other contained no iron. Samples of pipe were removed every month for 4 months and examined.

Coupons from an earlier study (10) of asbestos-cement pipe exposed to water over saturated with calcium carbonate were also examined to see how the initial stages of calcium carbonate coating compared with the initial stages of iron coatings.

ANALYSIS METHODS

After reviewing the literature available on studies of asbestos-cement pipe, it was apparent that the usual methods for evaluating the condition of A/C pipe, namely visual observation and thumbnail scratch tests, were not sufficiently quantitative for research comparisons. Two hardness tests and techniques using the scanning electron microscope (SEM) with X-ray elemental analysis were developed or adapted for studying the pipe pieces. Details of these analysis methods are to be published elsewhere (11). The Rockwell hardness tester was originally suggested in Ramaley (12). The durometer hardness tester as suggested in Ramaley (12) had a flat base area where the durometer was placed on

the sample. The curved surface of pipe caused variable readings of hardness. A modified durometer was constructed with a curved base to fit the curved pipe. A comparison of the durometers is shown in Figure 2. Estimates of the number of fibers exposed on the surface of a pipe piece were made using magnified images in the SEM. X-ray analyses of cross-sections of A/C pipe were used to measure the depth to which calcium had been lost from the pipe cement matrix attacked by aggressive water. X-ray analyses of the material at the surface of the pipe were used to estimate the amount of iron or other element coating the pipe.

RESULTS

The results of the hardness tests and microscopy examinations are given in Tables 2 and 3. Considerable differences were seen between the various pipe surfaces and coatings, but generally the coatings were found to be granular and porous in appearance. The coatings did not appear to be composed of layers as the scales on iron pipes had been described in the schematic produced by Sontheimer et al. (13).

The sample with the thickest coating had little iron in it. The pipe from system R where lime had been added in quantities high enough to cause calcium carbonate precipitation was covered with a white, granular coating shown to be composed mostly of calcium. X-ray diffraction using the Debeye-Scherrer method performed by the Department of Metallurgical Engineering, University of Arizona, confirmed that the coating was mostly calcite. The hardness tests indicated that the coating was soft in comparison to new, unused pipe but after scrapping away the coating, the pipe underneath gave hardness values similar to new pipe. The average thickness of the coating was found to be 0.9 mm.

The pipe from system Q had also been exposed to nonaggresive water (AI > 12) but was covered with a orange-yellow coating. Examination by microscopy and X-ray analysis showed that the coating was composed of fine crystals containing both iron and calcium. There was no evidence of fibers on the surface and no evidence of calcium loss from the pipe wall.

The pipe piece from system P had the appearance of new pipe but was slightly softer and showed a small loss of calcium from the pipe wall. Microscopy showed a thin but complete covering of fine crystals on the surface. No fibers were visible. The calcium loss may have resulted from leaching during a time or times when the water was undersaturated with calcium carbonate. The water quality of this system had varied over time.

In contrast to the coatings found on the pipes exposed to nonaggressive waters, the surface of two pipes exposed to aggressive water in systems J and M showed evidence of considerable numbers of exposed fibers. There was no evidence of iron coating except in very small pockets of the surface. Of more interest was the condition of the pipe pieces taken from systems K and L which also carried very aggressive waters. On both K and L samples an iron coating made of very fine crystals similar in appearance to that of system Q covered the surface. Few fibers were seen in either case and those evident were usually iron coated. The coating was composed primarily of iron rather than a mixture of iron and calcium as in system Q. Although the coatings covered fibers, they did not seal the pipe as evidenced by the calcium loss values. One part of the inner surface of the pipe from system L showed evidence of the iron coating peeling away from the pipe wall and exposing fibers. A partial protective coating was also seen on the pipe pieces from systems I and O. The pipe from system I showed a small calcium loss and fibers

just visible at the surface in some areas but not in others. Although the pipe from system O was relatively hard and showed no measurable calcium loss, one area of the pipe showed evidence of some fibers exposed.

The pipe in system N had been exposed to aggressive water for 20 years but had a hardness like that of new pipe and had few exposed fibers. The remarkable coating on this pipe was made of aggregate crystals larger than those forming the coatings of pipes from sytems K, L, and Q, but similar to the coating found on the pipe from system R except that the crystals contained primarily iron. X-ray diffraction analysis provided by the University of Arizona using the Debebye-Scherrer-Hull method concluded that the coating did not contain calcite or the iron minerals: siderite, goethite, magnetite, maghemite, or lepidocrocite, but that it might contain the iron mineral, hematite. The coating was found to contain a considerable amount of zinc. A review of the water quality data showed that the water being transported contained from 0.4 to 0.5 mg/L zinc. Zinc has been reported to precipitate onto the surfaces of A/C pipe when the pH is high and the water quality nonaggressive (3). In this system it apparently participated in the formation of a good coating under aggressive water conditions with a pH of 7.4, an alkalinity of 34 mg/l and calcium hardness of 30 mg/l as calcium carbonate.

The coupons from earlier experimental work by one of us (RNK (12)) provided some data on how the calcite coating is formed. Although the early conclusions were that there were no coatings formed on the "inert" pipe (asbestos-cement, cast-iron cement lined, and tar coated pipes), closer examination with optical and electron microscopy showed that in comparison to the available unused A/C pipe coupons from his experiments, a coating was being formed on the coupon, A-2-O, exposed for 32 days to water overstaturated with calcium carbonated (Stability Index = +1.1, AI = 13.1) (Tables 4 and 5). This coating was not a uniform layer over the whole surface but granular aggregates of crystals distributed over the surface. There was no evidence of exposed fibers. The average thickness of the white coating was 0.2 mm. There was no evidence, however, of a coating on the coupon, C-1-F, exposed to water that was maintained at a slightly oversaturated condition (SI = +0.1, AI = 12.1) for 33 days. There were some fibers showing. These examinations suggested that the coatings of calcium carbonate and iron-containing materials begin in similar ways.

The results of a comparison of the coupons from the experimental tanks shown in Figure 3 are given in Tables 6 and 7. After 1 week of the 4-month test of initial corrosion a few fibers were visible on the surface of the pipe coupon but generally the coupon had the look of new pipe. After 1 month there were a considerable number of fibers on the surface and evidence of some pitting of the surface. After 2 months, there appeared to be layers of fibers in some areas, although some flat areas of cement-aggregate were visible. After 3 and 4 months of exposure to very aggressive water, the surface essentially looked the same as after 2 months. The hardness tests showed some variability but there was a definite difference between the hardness of the new pipe and that of the coupon exposed for 3 months. The calcium loss was measurable after 3 months.

After 1 month in the recirculating tank containing 0.3 mg/L of iron, the surface of the coupon still looked like new pipe except for some slight evidence of pitting. About 10% of the surface was coated with iron-containing crystals mostly in the pitted areas. Few fibers were seen. After 2 months there were more iron-containing crystals but still

only in the pitted areas. Few fibers were seen. After 3 months there was iron coating on most areas. An occasional fiber as visible protruding up from the surface. In the last coupon, (4 months) the iron containing crystals covered 80-90% of the surface in some places and 50-60% in other areas. No fibers were seen protruding but some fibers were visible at the surface. Some of these were partially covered with crystals containing iron. Regression analysis of the X-ray elemental data suggests a linear relationship between the percentage of iron on the surface and time of exposure.

DISCUSSION

This research has shown that iron coatings can be formed on A/C pipe under aggressive water conditions and that the coatings can prevent fibers from being exposed on the surface. There is suggestion, however, that the coatings do not necessarily stop calcium from being leached from the pipe and a resulting soft layer of pipe can be formed between the coating and solid pipe. There is some additional evidence that rapid velocity changes in water flow or erosion action by sand in the water will disrupt the coating and allow fibers to fall into the water.

At this time there is no perfect way of assessing the potential for fiber release from A/C pipe on the basis of water quality data alone. There is good evidence that fibers are not released when the water being carried is classified as non aggressive according to the AI. However, the converse is not necessarily true; aggressive water does not automatically mean fibers in the water of an A/C pipe system. The relationship between iron in the water and iron coatings needs to be studied further before this factor can be included in an index of potential fiber release.

Physical examination of the pipe surface using a modified durometer can provide a quantitative measure of the degree to which a pipe has been attacked but the values determined are not necessarily related to potential fiber release because a soft iron coating may prevent fibers from being exposed on the surface of the water. Further research is needed to determine what water system conditions would contribute to a disruption of an iron coatings on softened pipe and release of fibers into the water.

CONCLUSIONS

Coatings containing iron were found on asbestos-cement pipes exposed to a range of water qualities from very aggressive to nonaggressive. Under aggressive water conditions iron coatings had a granular, porous structure that prevented asbestos fibers from being exposed on the surface of the pipes but did not necessarily prevent leaching of calcium from the interior of the pipe (several millimeters from the surface).

Coatings of iron were formed not as a continuous film but as crystals of an iron compound accumulating on the surface of the pipe. The percentage of iron on the surface increased as a linear function over time.

A modified durometer showed promise as a hand-held instrument for the assessment of A/C pipe softening in the field. The numerical value of hardness given was related to the amount of calcium leached from the pipe but was not directly related to the amount of fiber exposed on the surface of the pipe.

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$$A.I. = pH + \log_{10} (A \times H)$$

Where: pH is measured in recognized pH units
A is total alkalinity in mg/L as $CaCO_3$
H is calcium hardness, Ca in mg/L as $CaCO_3$

Interpretation: A.I. < 10 very aggressive
10 < A.I. < 12 moderately aggressive
A.I. > 12 nonaggressive

FIGURE 1. Aggressiveness Index (A.I.)

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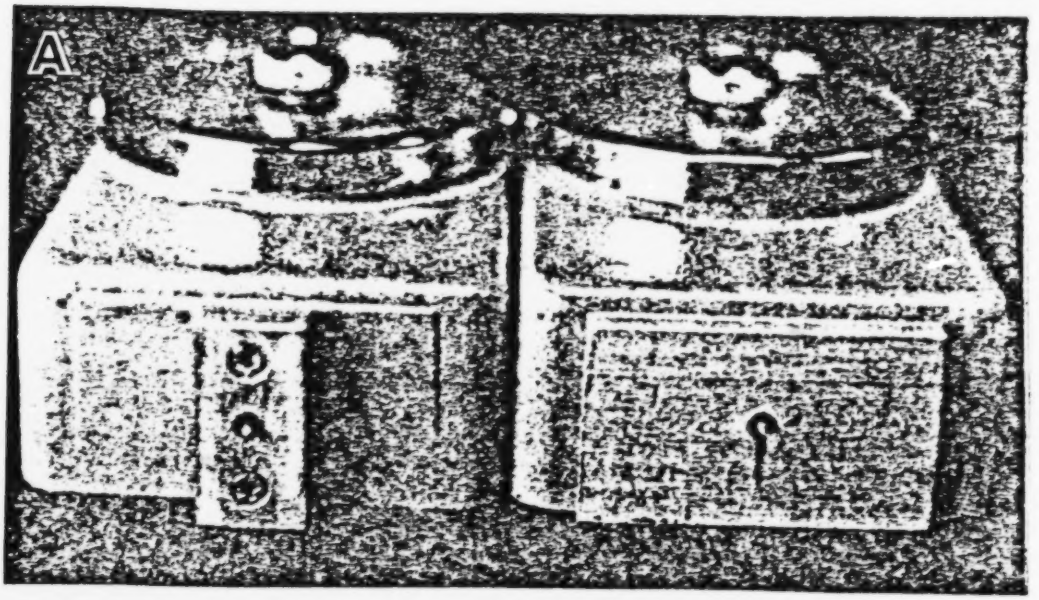

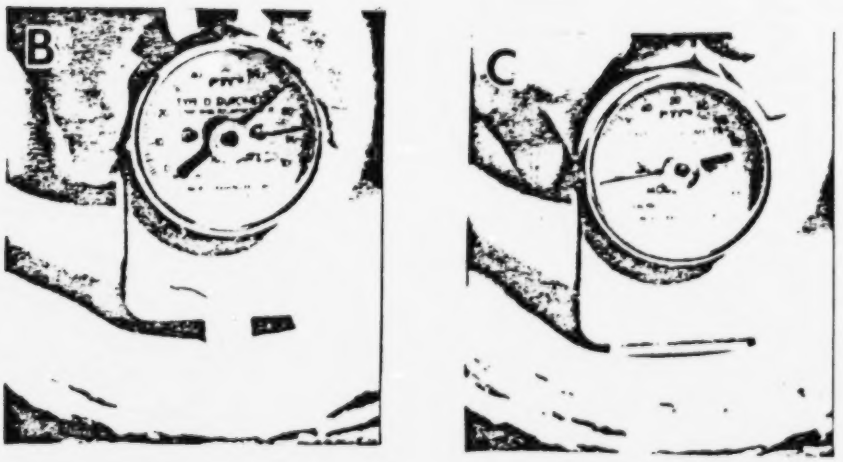

FIGURE 2. Comparison of Durometers. (a. modified base (left), standard base (right). b. modified durometer. c. standard durometer.)

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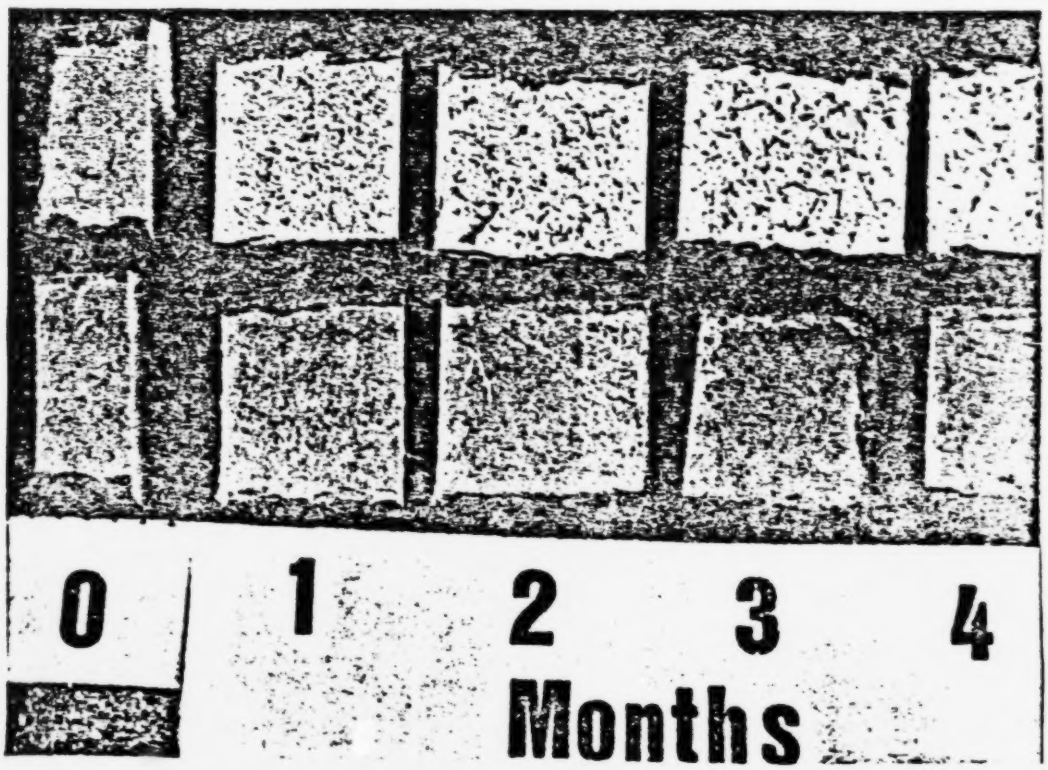

FIGURE 3. Coupons from Experimental Tank Tests (top-corrosion test, bottom-iron coating test, both with AI < 10.0)

Table 1.
A/C Pipe Samples From the Field

Water Distribution System	Aggressive Index	Visual Evidence of Coat	Age of Pipe
J*	5.7	no	5 yrs
K	7.5	yes	15 yrs
L	9.5	yes	10 yrs
M	10.0	no	40 yrs
N	10.4	yes	20 yrs
I*	11.6	yes	
O	11.8	partial	15 yrs
P	12	no	10 yrs
Q	>12	yes	18 yrs
R	13	yes	20 yrs

* same systems I and J as in Buelow et al. (1)

Table 2.
Results of Testing Field Samples

System Code	A.I.	% of Surface Area Covered by Fibers	Modified Shore D Durometer	Rockwell 'L' Scale	Calcium Loss (mm)
1. System J*	5.7	38	65	-49	2.4
2. System K	7.5	1	66	-66	3.3
3. System L	9.5	1-29	79	-38	2.4
New Pipe		2	96	102	0.0
4. System M	10.0	28	75	37	2.8
5. System N	10.4	0	95	99	0.0
6. System I*	11.6	3	88	86	0.8
7. System O	11.8	1-11	93	97	<.1
New Coupling		0	97	102	0.0
8. System P	12	2	92	91	0.7
9. System Q	>12	4	94	99	0.0
10. System R	13	0	88	89	+.9
New Pipe		0	98	103	0.0

* same systems I and J as in Buelow et al. (1)

Table 3.
X-Ray Results of Testing Field Samples

Town/Utility	A.I.	Average X-ray Analyses Volume of Surface Layer (Mass Fraction) Mg	Si	S	Ca	Fe	Zn
1. System J*	5.7	.12	.71	.01	.05	.07	<.005
2. System K	7.5	.05	.48	.01	.03	.32	<.005
3. System L	9.5	.21	.59	.01	.05	.11	<.005
New Pipe		.04	.15	.13	.58	.04	<.005
4. System M	10.0	.09	.56	.03	.08	.11	<.005
5. System N	10.4	.02	.29	.01	.37	.28	.01
6. System I*	11.6	.05	.50	.01	.20	.15	<.005
7. System O	11.8	.08	.59	.01	.12	.15	<.005
New Coupling		.05	.20	.13	.53	.04	<.005
8. System P	12	.01	.25	.01	.38	.03	<.005
9. System Q	>12	.06	.28	.01	.09	.46	<.005
10. System R	13	.05	.06	.01	.89	.03	<.005
New Pipe		.05	.18	.11	.56	.03	<.005

* same systems I and J as in Buelow et al. (1)

Table 4.
Results of Testing Laboratory Samples

Investigator	Initial AI	% of Surface Area Covered by Fibers	Modified Shore D Durometer	Rockwell 'L' Scale	Calcium Loss (mm)
Kinman					
Unused	----	1%	97	98	0.0
A-2-0	13.1	0%	94	92	+.2
C-1-F	12.1	2%	92	93	<.1

Table 5.
X-Ray Results of Testing Laboratory Samples

Investigator/Coupon	Initial AI	Average X-ray Analyses Volume of Surface Layer (Mass Fraction) Mg	Si	S	Ca	Fe	Zn
Kinman							
Unused	----	.07	.43	.01	.39	.04	<.005
A-2-0	13.1	.06	.34	.01	.47	.06	<.005
C-1-F	12.1	.08	.47	.01	.30	.10	<.005

Table 6.
Results of Testing Experimental Samples

Investigation	% of Surface Area Covered by Fibers	Modified Shore D Durometer	Rockwell 'L' Scale	Calcium Loss (mm)
1. Phase 3 Iron Coating Test				
1 week	2%	--	--	--
4 weeks	1%	95.2	102	<.1
8 weeks	1%	92.4	100	<.1
12 weeks	1%	91.0	99	.1
16 weeks	>1%	90.7	99	.1
2. Phase 3 Corrosion Test				
1 week	2%	--	--	--
4 weeks	20%	94.6	100	<.1
8 weeks	38%	91.2	99	.1
12 weeks	42%	92.2	98	.2
16 weeks	50%	91.0	99	.2

Table 7.
X-Ray Results of Testing Experimental Samples

Investigation	Average X-ray Analyses Volume of Surface Layer (Mass Fraction) Mg	Si	S	Ca	Fe	Zn
1. Phase 3 Fe Test						
1 week	.12	.62	.01	.08	.08	<.005
4 weeks	.14	.61	.01	.02	.12	<.005
8 weeks	.14	.57	.01	.03	.15	<.005
12 weeks	.12	.55	.01	.03	.19	<.005
16 weeks	.13	.56	.01	.02	.23	<.005
2. Phase 3 Corrosion Test						
1 week	.10	.68	.01	.06	.04	<.005
4 weeks	.16	.63	.01	.03	.07	<.005
8 weeks	.15	.62	.01	.03	.09	<.005
12 weeks	.17	.61	.01	.03	.09	<.005
16 weeks	.17	.64	.01	.02	.08	<.005